

A STRATEGIC ASSESSMENT OF FIRE HAZARD IN MONTANA

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EXECUTIVE SUMMARY

Problem And Approach

Severe and extensive wildfires in the summer of 2000 provide harsh testimony to the hazardous conditions extant over large areas of the Montana landscape. These events have galvanized public support for management actions. However, developing plans to address hazard at a strategic level requires a fundamental understanding of the problems at hand, and the potential effectiveness and costs of treatments to address them.

Consequently, we designed this study to meet the following objectives:

- Profile forest conditions in Montana
- Assess fire hazard
- Evaluate effectiveness of hazard reduction treatments
- Estimate treatment costs.

Forest Inventory and Analysis (FIA) data for the state of Montana provided us the means to profile forest conditions statewide, and then assess fire hazard. We evaluated fire hazard using the Fire and Fuels Extension (FFE) to the Forest Vegetation Simulator (FVS). Hazard was quantified in terms of Crowning Index, which is the windspeed necessary to sustain a crown fire once a fire has reached the main canopy. Crowning Index values less than 25 miles per hour (mph) were rated high hazard, 25-50 mph as moderate hazard, and greater than 50 mph as low hazard.

Fire hazard was evaluated for nine major forest types; however, our analysis primarily focused on short-interval, fire-adapted ecosystems. In Montana, these are the high/moderate-hazard Ponderosa Pine, Douglas-fir, and Dry Lower Mixed Conifer (PP/DF/DLMC) forests where people and property are most at risk.

We collaborated with representatives from federal, state, tribal, and industrial land management entities to develop three treatment prescriptions for reducing fire hazard:

- 1) Thin-from-Below: remove all trees smaller than 9"
- 2) 50% Basal Area Removal: remove the smaller half of basal area
- 3) Comprehensive: ecologically-based; reserve a target basal area of 40-50 ft²/acre, primarily comprised of larger trees.

Fire hazard (i.e., Crowning Index) for each of the three treatments was evaluated immediately after treatment using FFE. Treatment costs and revenues were estimated using a harvest cost model and long-term data bases maintained at the University of Montana. Land management agencies and the private sector provided cost estimates for treating activity fuels.

We used FVS to project post-treatment conditions forward 30 years for each of the treatment alternatives, and then reevaluated Crowning Index again in the year 2030 using FFE. Projection allowed us to evaluate the durability of hazard reduction treatments through time.

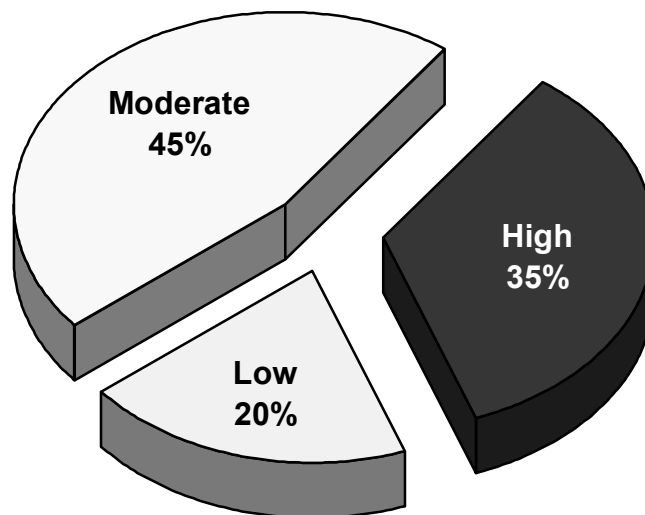
Findings

Montana has nearly 22.3 million acres of forestlands, 82 percent of which have a high/moderate fire hazard rating. Nearly 9.3 million acres are classified as short-interval, fire-adapted ecosystems. About 7.5 million acres (or 80 percent) of these are in high/moderate fire hazard condition (Figure 1).

Our analysis shows that hazard reduction treatments differ dramatically in their potential to reduce crown fire hazard. The Thin-from-Below treatment only increases average Crowning Index in treated stands from 27 to 34 mph (Table 1), and moves only 13 percent of treated acres into the low hazard category (Table 2). The Comprehensive treatment, in contrast, increases average Crowning Index to 82 mph, and moves 90 percent of treated acres into a low hazard condition (Table 2).

We also found that the Comprehensive prescription designed to reduce hazard and restore sustainable stand conditions would yield an average positive net revenue of \$624 per acre treated (Table 1). Some stands would require an expenditure, but the value of timber products removed would cover harvest, onsite fuels treatment, and haul costs on over half of the acres treated. In contrast, net revenues were always negative for the Thin-from-Below prescription, and negative for most acres treated with the 50% Basal Area Removal approach.

Figure 1. Proportion of Montana's short-interval fire-adapted forests (PP, DF, DLMC types) by fire hazard rating.



Total PP, DF, DLMC forestland = 9.3 million acres

Table 1. Average Crowning Index, net revenues, and percentage of acres with positive net revenues, for three hazard reduction treatments.

Hazard Reduction Treatment	Crowning Index		Average Net Revenues per Acre	Percent of Acres with Revenues Exceeding Costs
	Pre-Treatment 2000	Post-Treatment 2000		
Thin-from-Below to 9"	27	34	-\$664	0%
50% Basal Area Removal	25	50	-\$294	20%
Comprehensive	26	82	\$624	51%

Our reevaluation of Crowning Index in the year 2030 showed that the long-term effects of the various hazard reduction treatments continued to vary widely. Average Crowning Index following the Thin-from-Below treatment nearly reverted back to the high hazard category by 2030 (Tables 1 and 2). In contrast, the average Crowning Index for the Comprehensive treatment decreased to 64, still solidly in the low hazard category. Long-term effects of the 50% Basal Area Removal treatment were only moderately better than those of the Thin-from-Below treatment.

Table 2. Average Crowning Index and percent of acres rated low hazard immediately after treatment (2000) and 30 years after treatment (2030).

Hazard Reduction Treatment	Crowning Index		% of treated acres rated low hazard post-treatment (2000)	% of treated acres rated low hazard 30 years post-treatment (2030)
	Immediately post-treatment (2000)	30 Years post-treatment (2030)		
Thin-from-Below to 9"	34	30	13%	3%
50% Basal Area Removal	50	38	44%	10%
Comprehensive	82	64	90%	73%

One striking effect associated with the two prescriptions aimed at removing small trees is that substantial acreages would again need hazard reduction treatment at the end of the 30-year period. Only three percent of the acres receiving the Thin-from-Below treatment and 10 percent receiving the 50% Basal Area Removal treatment would remain in the low hazard category in 2030 (Table 2). However, 73 percent of the acres treated with the Comprehensive prescription would still have a low fire hazard rating 30 years later.

Conclusions

Results of this study show that whether the fire problem is viewed from a hazard reduction, ecological condition, or financial standpoint, the Comprehensive approach is clearly superior to prescriptions that focus only on removing small trees. The Comprehensive prescription achieves far greater hazard reduction immediately post-treatment, and is far less expensive to employ. It is also superior in terms of longevity and extent of effectiveness compared to the treatments with a singular focus on small-tree removal.

HIGHLIGHTS

- Over 80% of all forested lands in Montana rated high/moderate for crown fire hazard.
- 9.3 million acres of Montana forestland fell within short-interval, fire adapted ecosystems - 7.5 million acres of which were high/moderate hazard.
- Alternative treatments differed dramatically in their effectiveness in reducing crown fire hazard.
- A Comprehensive prescription designed to reduce hazard and restore sustainable structure was superior to prescriptions designed to remove smaller trees only.
- In dense, multi-storied ponderosa pine/Douglas-fir stands in western Montana, the Comprehensive treatment increased Crowning Index an average of 68 mph, whereas the Thin-from-Below treatment only increased Crowning Index by 2 mph.
- 90% of the acres receiving the Comprehensive treatment rated low hazard following treatment, whereas only 13% rated low hazard following the Thin-from-Below treatment.
- The Comprehensive prescription not only provided the greatest hazard reduction; it also yielded an average net revenue of \$624 per acre from timber removed as a treatment byproduct.
- Over 70% of the acres receiving the Comprehensive treatment remained low hazard 30 years after treatment. Only 3% of the acres receiving the Thin-from-Below treatment were rated low hazard 30 years later.

INTRODUCTION

Severe "fire years" in Montana in 1988 and 1994, and most recently in the summer of 2000, provide harsh testimony to the hazardous forest conditions over large areas of the Montana landscape. The fires of 2000 are especially notable, not just in terms of acres burned, but particularly because of the significant damage to property and associated threats to people.

Three major fire seasons in a dozen years have raised public and agency consciousness about wildfire to unprecedented levels. There is now both the public support and political will for major initiatives to address this regional concern (Devlin 2001, Western Governors' Association 2001). However, planning to address fire hazard at a strategic level requires a fundamental understanding of the nature and scope of the problem at hand. For example, what forest types and conditions are most vulnerable to fire? What kinds of treatments are most effective in reducing fire hazard, and how much do they cost? How durable are the effects of these treatments over time?

Absence of a detailed, systematic, and uniform forest inventory for all acres and ownerships has heretofore precluded a comprehensive analysis of fire hazard in Montana. However, recent availability of Forest Inventory and Analysis (FIA) data across all ownerships makes possible a strategic assessment of fire hazard at the state-wide level. Indeed, FIA data provided the basis for the analysis that follows.

Objectives

The overall goals of our project were to profile forest conditions and fire hazard in Montana, and evaluate the potential effectiveness and costs of hazard reduction treatments. Specific objectives were to:

1. Describe and quantify forest conditions in Montana, and rate for fire hazard
2. Develop alternative treatment prescriptions and evaluate their effectiveness at reducing hazard, both now and 30 years in the future
3. Determine harvest and prescribed burning costs associated with treatment
4. Determine the potential revenue from timber products generated by the hazard reduction treatments.

METHODS

FIA data on the composition and condition of forestlands in Montana were obtained from the USDA Forest Service Interior West Resource Inventory, Monitoring, and Evaluation (IWRIME) program based in Ogden, Utah. This unit conducts permanent plot inventories in Montana and other Rocky Mountain states.

The national forest inventory data used in this study were collected between 1993 and 1997 for western Montana, and between 1996 and 1998 for eastern Montana. All other ownerships in the state (with the exception of National Park Service lands) were inventoried in 1988-89. Our study excludes forestland in national parks such as Glacier and Yellowstone. Other reserved forestlands, such as designated wilderness areas, are included in the inventory information. The lone exception is a portion of the Mission Mountain Wilderness, located on Confederated Salish and Kootenai tribal lands.

The most important characteristics of IWRIME data are their uniformity and comprehensiveness. While forest conditions can vary greatly, the IWRIME data set allows description and comparison within and across regions and ownerships, using common measures gathered through consistent, scientific sampling methods.

We worked with data from 1,936 sample points in western Montana, and 1,807 points in eastern Montana. A sample point, or "cluster," was our basic unit of analysis. Each cluster was regarded as a stand, and typically represents about 6,000 acres of forestlands. Variables recorded at each sample point fall into one of four categories:

- Location variables: owner, elevation, distance to road, etc.
- Condition variables: condition class, slope, aspect, land use, etc.
- Tree/stand variables: diameter, height, basal area, volume, species, etc.
- Understory vegetation variables: cover of three vegetative layers, i.e., tree cover, shrub cover, forb cover; also reports grass cover.

Fire Hazard

Potential fire hazard was analyzed for each cluster using the Fire and Fuels Extension (FFE; Beukema et al. 1997, Scott, and Reinhardt 2001) to the Forest Vegetation Simulator (FVS; Stage 1973, Crookston 1990, Van Dyck 2000). This model (extension) estimates crown fire hazard based on tree, stand, and site characteristics, and expresses fire hazard/effects in terms of Crowning Index, Torching Index, and Basal Area Mortality.

Crowning Index, defined as the windspeed necessary for a fire that reaches the canopy to continue as a crown fire, was the primary variable used to report hazard in this study. We defined high-hazard forest conditions as having a Crowning Index <25 mph, moderate hazard from 25 to 50 mph, and low hazard >50 mph. Once the Crowning Index was calculated for each cluster, the entire inventory was sorted by various combinations of forest type,

density, structure, region, and ownership to display fire hazard by the categories of interest. In addition, the FVS model was used to project forest conditions 30 years into the future (i.e., from 2000 to 2030), at which time fire hazard was again assessed using FFE.

Forest Types

Conditions vary greatly across the millions of acres and approximately 7,000-foot elevation range of forestlands in Montana. We classified these diverse conditions into forest types that would be recognizable and meaningful to managers. We employed a hierarchical model to assign each of the more than 3,700 FIA sample clusters in Montana to one of nine forest types or one of two miscellaneous categories. Forest type assignments were based on majority (or plurality) basal area composition of key tree species, and on habitat type (Pfister et al. 1977) criteria. Any cluster not meeting minimal requirements for any of the nine forest type designations was classified either as "Other" or "Non-stocked," depending on specific attributes.

Density

FIA clusters (stands) were assigned to one of three density categories (Low, Moderate, or High) using a three-step process. Data were first sorted by region (west vs. east of the Continental Divide), and then by forest type within region. Finally, density classes were formulated by subdividing the population of clusters within each region/forest type combination into thirds based on the full range of basal area densities for that combination.

Structure

Each FIA cluster was assigned to one of four structural classes (Scattered, One-story, Two-story, or Multi-story). We formulated structural classes for each forest type primarily based on size class and basal area attributes. Five general size classes of trees were recognized: Sapling (<5.0" DBH), Pole (5.0"-8.9"), Medium (9.0"-14.9"), Large (15.0"-19.9"), and Very Large (≥ 20.0 "). Clusters with $<25 \text{ ft}^2/\text{acre}$ of basal area were assigned to Scattered structures, since such conditions are too open to recognize distinct layers or strata. Clusters with only one recognizable size class were assigned One-storied structures; clusters with two distinct size classes were assigned to Two-storied structures; and clusters with three or more size classes were assigned to Multi-storied structures. A minimum basal area of $10 \text{ ft}^2/\text{acre}$ was required for Pole, Medium, Large, or Very Large size classes to be recognized as an individual size class or stratum. For Saplings, a minimum of $5 \text{ ft}^2/\text{acre}$ was required to be recognized as a distinct size class.

Hazard Reduction Treatments

We focused our evaluation of fire hazard on short-interval, fire-adapted ecosystems. In Montana, these ecosystems are primarily comprised of Ponderosa Pine (PP), Douglas-fir (DF), and Dry Lower Mixed Conifer (DLMC) forest types. Short-interval, fire-adapted ecosystems were identified as highest priority for

treatment in "Protecting People and Sustaining Resources in Fire-Adapted Ecosystems -- A Cohesive Strategy" (USFS 2000, DOI 2001). Frequent, low-intensity fires were the primary agent that shaped these forests historically, and kept them resistant to severe fires.

While dense, multi-storied conditions are a primary concern in short-interval, fire-adapted ecosystems, they are neither unexpected nor uncommon in the Moist Lower Mixed Conifer, Upper Mixed Conifer, and Spruce/Fir forest types. Fires typically occur in these forests at relatively long intervals, and burn with high severity when they do (Fischer and Bradley 1987). Wildfires in moister and higher elevation forests are not as often a direct threat to people or property, and historically burned as mixed-intensity or stand-replacement events when they did occur (Fischer and Bradley 1987). Consequently, the short-interval, fire-adapted forests were deemed highest priority for detailed evaluation by the Technical Contact Team.

Three general types of hazard reduction treatments were evaluated. A common objective of all three is to reduce density and create a discontinuity in the vertical fuel profile by removing the ladder fuel component, typically comprised of sapling- and pole-sized trees. One such approach is thinning-from-below to some given diameter limit, a treatment that has been widely recommended (Babbitt 1997, Dombeck 1997). We used a diameter limit of 9" in this analysis. A second approach is to remove some given percentage of the existing basal area (e.g., 33 to 50 percent), from the smallest trees up (Martin 2000). A target of 50 percent basal area removal was used in this analysis.

A third general approach focuses on restoring sustainable structure (and ultimately ecological function), and therefore focuses on the trees to leave in terms of a target density, diameter distribution, and species composition (Fiedler et al. 1999). Trees are marked for leave in the sizes, numbers, species, and juxtaposition that will go furthest toward restoring a sustainable structure, given existing stand conditions. Most of the 40 to 50 ft²/acre target reserve density is comprised of larger trees, although some trees are marked for leave throughout the diameter distribution. This density range is sufficiently low to reduce fire hazard, increase tree vigor, spur development of large trees, and induce regeneration of seral species (Fiedler 2000). A low thinning is used to remove small trees, and improvement/selection cutting is applied in the mid- and upper canopy to reduce fire hazard, remove late-successional species (if present), and promote regeneration of ponderosa pine or western larch.

All three treatment prescriptions were applied to the Ponderosa Pine, Douglas-fir, and Dry Lower Mixed Conifer forest types. The Thin-from-Below and 50% Basal Area Removal prescriptions were applied similarly in all three types. However, the Comprehensive prescription differed slightly, with a target reserve density of 40, 45, or 50 ft²/acre for the Ponderosa Pine, Dry Lower Mixed Conifer, and Douglas-fir forest types, respectively.

Treatment Costs and Product Revenues

We did not consider treatment costs or potential timber product revenues when selecting or developing the alternative hazard reduction treatments for this study. The treatments we evaluated are either commonly used for hazard reduction, or were designed specifically to reduce hazard and enhance sustainability. However, because cost is a major factor influencing the potential implementation of hazard reduction treatments, we analyzed costs after the prescriptions were developed and modeled. In calculating net revenue we examined both treatment cost and the potential value of timber generated as a by-product of treatments.

Treatment Costs

Costs associated with implementing hazard reduction treatments include costs of removing timber to reduce fuel loading, slashing activity fuels, and prescribed burning of slash. We estimated harvest and haul costs using a recently completed predictive logging cost model applicable to hazard reduction and restoration treatments in Montana (BBER 2001a, Keegan et al. 2001a). We assumed treatments would occur on sites already accessed; therefore no road-building costs were included in the analyses. Data gathered from land management agencies and the private sector provided an additional basis for estimating costs associated with treating activity fuels.

Timber Product Values

Previous work shows that comprehensive prescriptions designed to reduce hazard and restore structure require removal of trees ranging from 4" to >20" in diameter (Fiedler et al. 1999 and 2001). Trees in this size range have two major product uses, sawtimber and pulpwood (Keegan et al. 2001b). Sawtimber is defined as trees that are of a size and quality suitable for lumber production. In Montana, sawtimber includes trees ≥ 10 " DBH. The major uses of sawtimber in Montana are saw logs for lumber production and veneer logs for plywood. Pulpwood is timber used to produce chips for pulp manufacture, and in Montana is generally comprised of material < 10 " DBH.

We developed sawtimber tree values for one-inch DBH classes by major species or species' groups from an extensive log price data system maintained by the University of Montana Bureau of Business and Economic Research (BBER 2001b), and from a sawmill simulation model (Wagner et al. 1998; Wagner et al. 2000).

We analyzed product values under two sawtimber market scenarios. The first was based on lumber and plywood prices from 1997-1999, a period of mixed conditions, with very strong markets in the first half of 1997 and most of 1999, and substantially weaker markets in 1998 due to the Asian financial crisis. The second sawtimber value scenario used delivered log prices that were 80 percent of the 1997-1999 period. This second scenario reflects market conditions that are weaker than those experienced since 1991. Adjustments were also made to reflect lower values for certain species in eastern Montana.

Historically, the market for roundwood pulpwood has been very sporadic, and nonexistent at times. For this reason, each

sawtimber market scenario was run with and without a pulpwood market. In our analyses for this report we assumed 1997-1999 market conditions, without a pulpwood market.

The relationship between milling capacity and the volume of timber available to the industry was assumed to remain constant under all market conditions. If a significant proportion of acres rated high/moderate for fire hazard were treated over a short period, large volumes of additional material could potentially come on the market, thus dampening prices. However, we assumed that increases in harvested timber volume would phase in gradually and reach a sustainable level. This in turn would lead to a gradual and commensurate increase in industry size.

RESULTS

Forest Types

Our analysis of FIA data for Montana shows that there were approximately 22.3 million acres of forestland in the state - 21.5 million of which were forested (Table 3). The three forest types (Ponderosa Pine, Douglas-fir, and Dry Lower Mixed Conifer) of greatest management concern in terms of fire hazard collectively occupied 9.3 million acres. About 775,000 acres were classified as "Other" since they did not meet criteria for any individual forest type. Five of the forest types (PP, DF, LP, MLMC, and SF) comprised at least one million acres each of forestland in Montana (Table 3). Detailed breakdowns of acreages of forest types by region, ownership, density, and structure are shown in Appendixes 1.a, b, c, and d.

Table 3. Acreages of major forest types in Montana.

Forest Type	Acres
Ponderosa Pine (PP)	2,841,185
Douglas-fir (DF)	6,176,632
Dry Lower Mixed Conifer (DLMC)	265,688
Western Larch (WL)	533,637
Lodgepole Pine (LP)	4,344,061
Moist Lower Mixed Conifer (MLMC)	1,375,005
Upper Mixed Conifer (UMC)	693,436
Spruce/Fir (S/F)	3,867,859
Timberline (TL)	588,257
Other (OTHR)	774,466
Total forested acres	21,460,226
Non-stocked (NS)	814,067
Total forestland	22,274,293

The federal government owns 14.8 million acres (69 percent) of the 21.5 million forested acres in Montana, 25 percent is privately owned, and the remaining 6 percent is in other ownership, which includes tribal and state lands (Appendix 2).

No clear patterns in forest conditions (i.e., density or structure) could be discerned by ownership alone. However, some interesting observations about the ownership of different forest types did surface in our analysis (Appendix 1.b). For example, about half (54 percent) of Montana's 9.3 million acres of short-interval fire-adapted forests (PP, DF, DLMC types) are federally owned, whereas 86 percent of Upper Mixed Conifer, 90 percent of Spruce/Fir, and 98 percent of Timberline forests are owned by the federal government.

Density and Structure

The range of basal area densities that were classified as High, Moderate, and Low varied among forest types and geographic regions (west and east of the Continental Divide) (Appendix 3). Basal area densities in the PP, DF, and DLMC types, which comprise the short-interval, fire-adapted forests, are shown in Table 4 to provide a frame of reference as to "How dense is dense?"

Table 4. Basal area ranges for Low, Moderate, and High density classes, by fire-adapted forest type (i.e., PP, DF, and DLMC types) and geographic region.

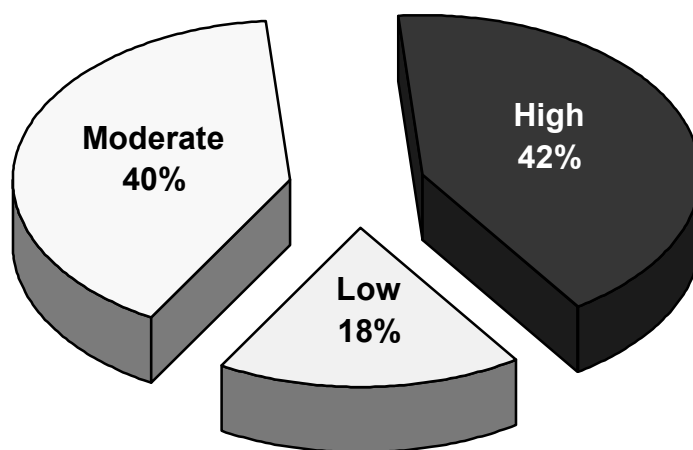
West of the Continental Divide				East of the Continental Divide			
Forest Type	Basal Area (ft ² /ac)			Forest Type	Basal Area (ft ² /ac)		
	Low	Mod.	High		Low	Mod.	High
PP	<50	50-100	>100	PP	<40	40-75	>75
DF	<90	90-150	>150	DF	<80	80-130	>130
DLMC	<80	80-130	>130	DLMC	<60	60-130	>130

The 21.5 million forested acres in the state were classified within one of four structural types: Scattered, One-storied, Two-storied, or Multi-storied. Approximately 9.5 million acres, or 44 percent of the forested acres, occurred in Multi-storied structures. About 28, 19, and 9 percent occurred in Two-storied, One-storied, and Scattered structures, respectively (Appendix 1.a).

Fire Hazard - Existing conditions

Results of our statewide analysis of crown fire hazard shows that 42 percent of Montana's forests were classified as high hazard, about 40 percent as moderate hazard, and only 18 percent as low hazard, based on Crowning Index (Figure 2).

Figure 2. Proportion of Montana's forestland by fire hazard rating.

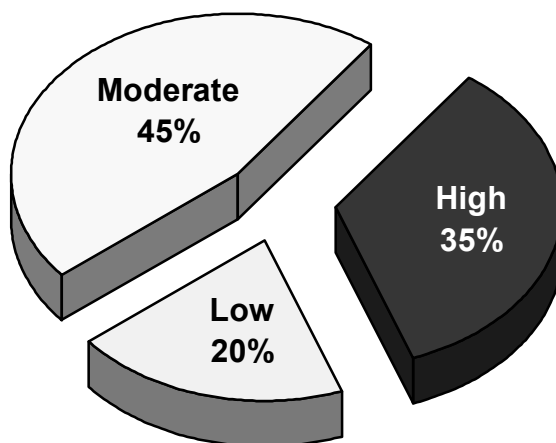


Total forestland = 22.3 million acres

Fire hazard ratings were similar for forestlands located west and east of the Continental Divide. About 39 percent of the forestlands west of the Divide were rated high hazard, about 45 percent were rated moderate, and approximately 16 percent were low hazard. Comparable numbers for forestlands east of the Divide were 45, 36, and 19 percent, respectively.

Existing fire hazard conditions in the 9.3 million acres of short-interval, fire-adapted forests approximated those for the state as a whole. Thirty-five percent of the acres of fire-adapted forests were rated high hazard, 45 percent as moderate hazard, and 20 percent low hazard (Figure 3). Of the nearly 5 million acres of PP, DF, and DLMC on federal land, 83 percent have a high or moderate fire hazard rating. This is in line with the fire hazard rating for these forest types across all ownerships, where 80 percent of short-interval, fire-adapted forests have a high/moderate fire hazard rating.

Figure 3. Proportion of Montana's short-interval fire-adapted forests (PP, DF, DLMC types) by fire hazard rating.



Total PP, DF, DLMC forestland = 9.3 million acres

Average Crowning Index values by region, ownership, density, and structure are shown in Appendix 4. The trends in Crowning Index across density and structural classes were especially notable. For example, looking at all forest types combined, average Crowning Index declined (i.e., hazard increased) across the range of densities from 47 at Low density to 29 at Moderate density, to 21 at High density. Similarly, average Crowning Index declined (and hazard increased) with increasing complexity in stand structure, from 34 to 32 to 25 for One-, Two-, and Multi-storied structures, respectively.

As the previous example shows, stand density is a particularly important attribute influencing Crowning Index. The potent effect of density is demonstrated in the following example. In stands with Multi-storied structures, 74 percent were rated high-hazard if they were also in the High density category, whereas only 26 percent of Moderate density stands and 0 percent of Low density stands in this structural class received a high-hazard rating. The importance of Density to Crowning Index is not unexpected, given that the calculation of Crowning Index within FFE is primarily dependent upon canopy bulk density.

Structure also had a substantial effect on Crowning Index in the 9.3 million acres of short-interval, fire-adapted forests. For example, in high-density conditions, 74 percent of the stands

with Multi-storied structures were rated high-hazard, whereas only 49 and 36 percent of Two-storied and One-storied stands received a similar rating, respectively.

Fire Hazard - Treatment Effectiveness

Short-term Effects on Fire Hazard

Hazard reduction treatments were evaluated for effectiveness if applied to the 7.5 million acres of high/moderate fire hazard forests in short-interval, fire-adapted ecosystems (PP, DF, and DLMC forest types). Our analysis showed that both average Crowning Index and the number of potentially treatable acres varied by prescription.

The effectiveness of treatments in reducing fire hazard (increasing Crowning Index) varied from minor for the Thin-from-Below treatment, to dramatic for the Comprehensive (Table 5). The Thin-from-Below treatment only increased average Crowning Index 7 mph, while the Comprehensive treatment created a 56 mph increase. The average Crowning Index of 34 resulting from the Thinning-from-Below treatment still left most stands in the moderate fire hazard range, and only 13 percent of treated acres moved to low hazard (Table 5). The Comprehensive treatment, in contrast, increased average Crowning Index to 82 mph, well into the low hazard range.

Table 5. Effects of hazard reduction treatments in PP, DF, and DLMC forest types.

Hazard Reduction Treatment	Pre-treatment Crowning Index (mph)	Post-treatment Crowning Index (mph)	% of treated acres rated low hazard post-treatment	High/moderate hazard acres treated
Thin-from-Below	27	34	13%	5.1 million
50% Basal Area Removal	25	50	44%	5.2 million
Comprehensive	26	82	90%	6.4 million

The number of forested acres potentially treatable varied as a result of silvicultural constraints placed on the different prescriptions, leading to slight differences among pre-treatment Crowning Index values (Table 5). An example of the constraints and their effects on acres treated can be seen in the differences between the Thin-from-Below vs. the Comprehensive treatment. The Thin-from-Below prescription could be applied to 5.1 million acres of the 7.5 million acres rated high/moderate hazard, while the Comprehensive treatment could potentially be applied to as many as 6.4 million acres. The lower acreage associated with the Thin-from-Below treatment primarily arises from restrictions to cutting in stands that would not have sufficient basal area remaining if all trees below 9" dbh were cut (e.g., a PP stand with no trees >6" dbh, or a DLMC stand with only 20 ft²/ac of basal area in trees >9"). The Comprehensive treatment could

still be applied in many of these stands, accomplishing fire hazard reduction by removing trees through thinning and improvement/selection cutting, as long as the target reserve basal area could be achieved.

Long-term Effects on Fire Hazard

Our evaluation of Crowning Index in the year 2030 showed that the long-term effects of the various fire-hazard treatments varied greatly, depending upon which prescription was implemented. However, the effectiveness of all hazard reduction treatments diminished somewhat through time.

Average Crowning Index following the Thin-from-Below treatment reverted from moderate hazard (34 mph) in 2000 nearly back to the high hazard category in 2030 (Table 6). Average Crowning Index for the Comprehensive treatment changed the most (numerically) over the 30-year period, from 82 to 64 mph, but still remained solidly in the low hazard category (Table 6). Changes associated with the 50% Basal Area Removal treatment were intermediate to the other two treatments.

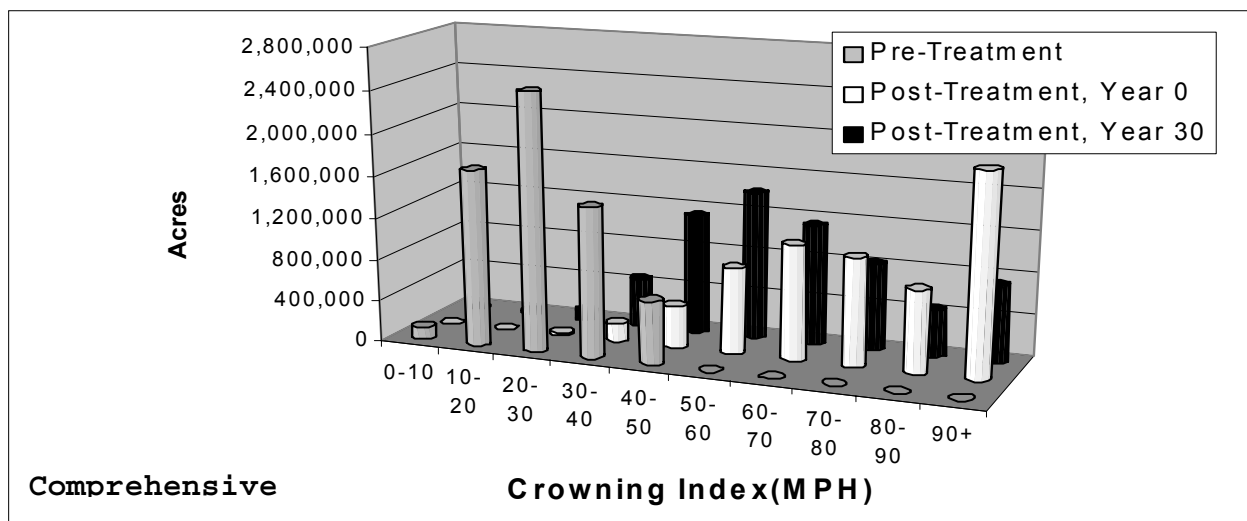
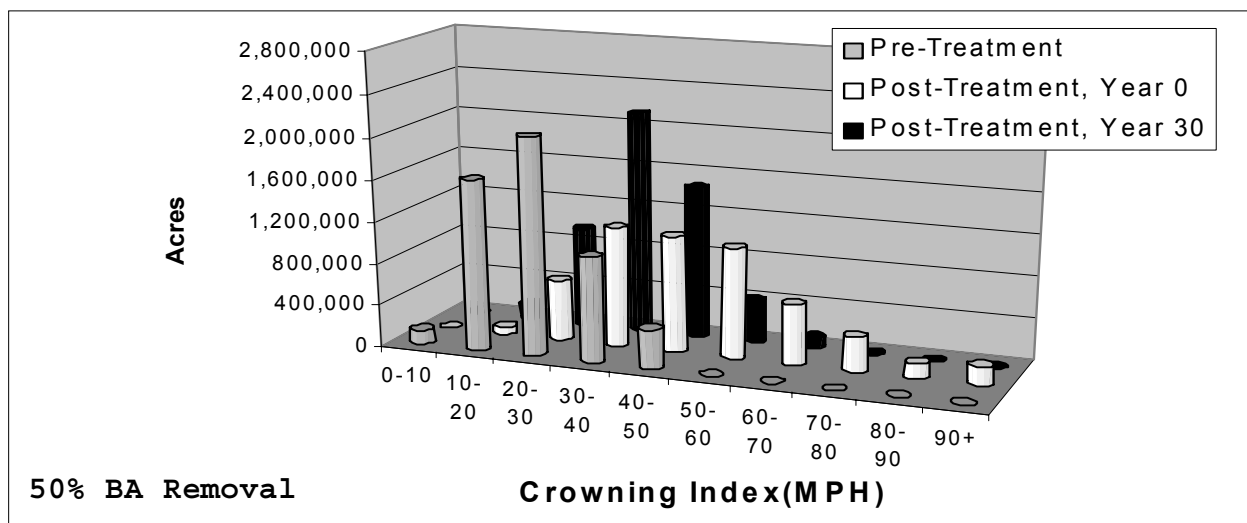
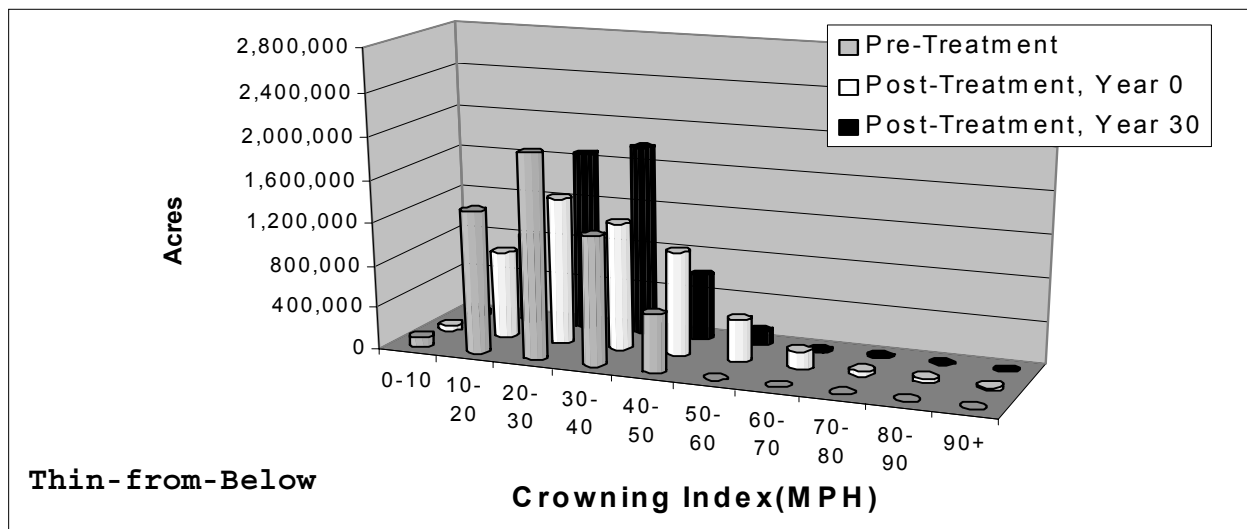
Table 6. Immediate and long-term effects of hazard reduction treatments in PP, DF, and DLMC forest types.

Hazard Reduction Treatment	Average Crowning Index immediately after treatment	Average Crowning Index 30 years after treatment	% of treated acres rated low hazard 30 years after treatment
Not Treated	26	26	<1%
Thin-from-Below	34	30	3%
50% BA Removal	50	38	10%
Comprehensive	82	64	73%

Changes in Crowning Index values for two of the three prescriptions indicate that substantial acreages would again need hazard reduction treatment at the end of the 30-year period. A mere three percent of the acres receiving the Thin-from-Below treatment and 10 percent receiving the 50% Basal Area Removal treatment would remain in the low hazard category in 2030 (Table 6). Meanwhile, 73 percent of the acres treated under the Comprehensive prescription would retain a low hazard rating 30 years after initial treatment.

The distribution of acres by Crowning Index values before treatment in 2000, after treatment in 2000, and in 2030 (Figure 4) shows that only the Comprehensive prescription provided lasting hazard reduction for treated stands. Differences are striking, and further illustrate the relative short- and long-term ineffectiveness of prescriptions aimed only at removing small trees.

Figure 4. Distribution of acres by Crowning Index values pre-treatment, post-treatment year 0, and post-treatment year 30 for three hazard reduction treatments.



Financial Aspects of Hazard Reduction Treatments

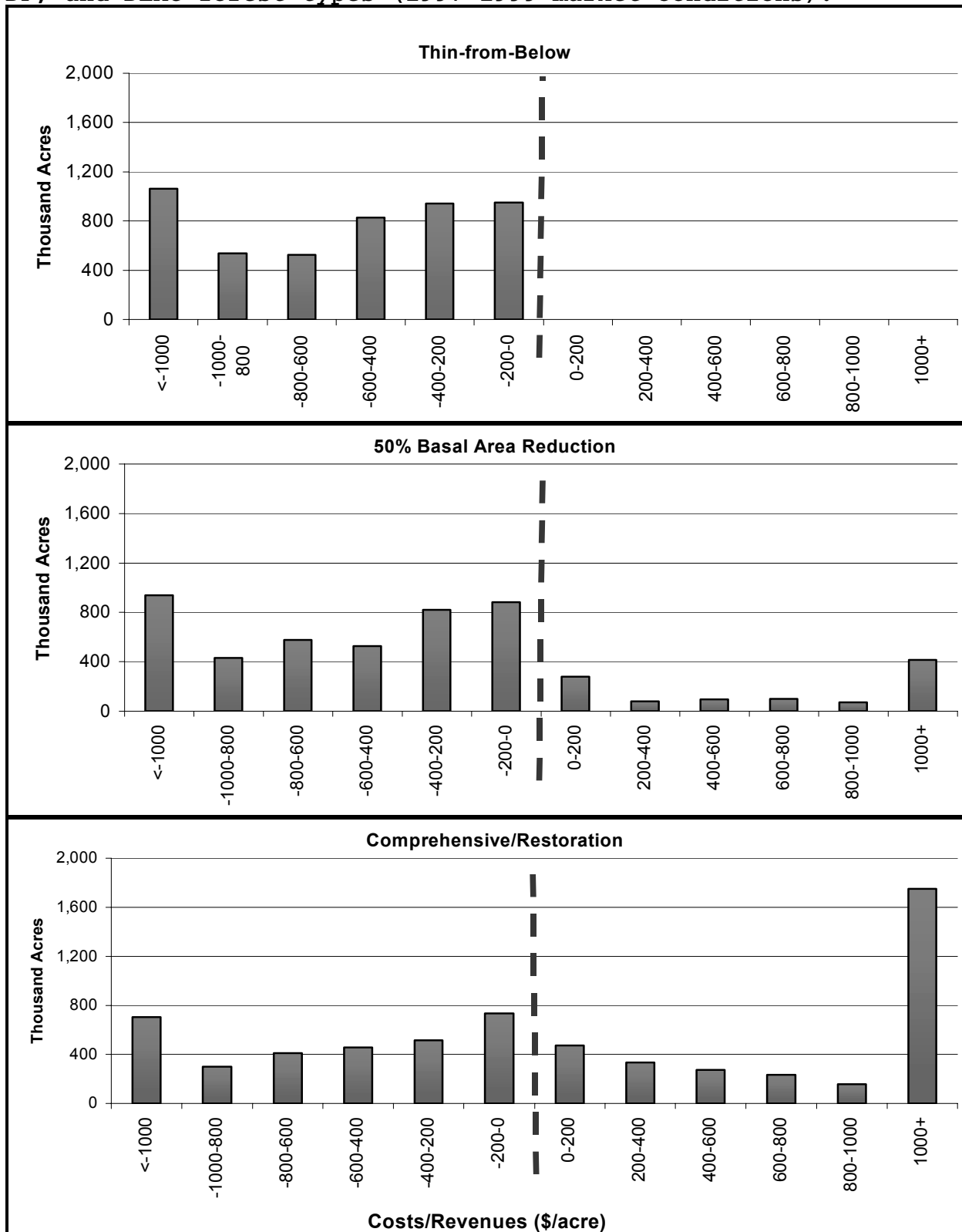
The three hazard reduction treatments differed greatly in terms of the volumes and value of timber products recovered in the process of treatment implementation. Based on 1997-1999 market conditions, applying the Thin-from-Below prescription required an average expenditure of \$664 per acre, and all acres treated with this prescription required expenditure to underwrite treatment costs (Table 7, Figure 5). Application of the 50% Basal Area Removal prescription required an average expenditure of \$294 per acre. A small proportion (20 percent) of the acres yielded timber product values sufficient to cover treatment costs. Applying the Comprehensive prescription to the suite of short-interval, fire-adapted forest acres with a high/moderate fire hazard rating yielded an average revenue of \$624 per acre treated (Table 7). The range of revenues was substantial, with some stands costing over \$1000 per acre to treat and others yielding positive net revenues of more than \$2000 per acre (Figure 5). More than half of the acres treated with the Comprehensive prescription yielded a value in timber (as treatment by-product) that exceeded all onsite hazard treatment costs (Table 7, Figure 5).

Table 7. Net revenues per acre, and percent of treated acres with positive net revenue, by hazard reduction treatment for high/moderate hazard conditions in PP, DF, and DLMC forest types (1997-1999 market conditions). Values are shown for Montana state-wide, as well as west and east of the Continental Divide.

Hazard Reduction Treatment	State-wide	West-side	East-side
Thin-from-Below (treated acres with revenue >\$0)	-\$664 (0%)	-\$740 (0%)	-\$578 (0%)
50% Basal Area Removal (treated acres with revenue >\$0)	-\$294 (20%)	-\$286 (23%)	-\$304 (17%)
Comprehensive (treated acres with revenue >\$0)	\$624 (51%)	\$1,022 (61%)	\$218 (40%)

Net revenues (+ or -) associated with implementing a given prescription differed substantially between forests located west and east of the Continental Divide. Stands west of the Divide had higher pretreatment volumes; therefore substantially higher volumes of trees with commercial value were removed to achieve desired objectives. As a result, application of the Comprehensive treatment netted an average of \$800 more per acre in west-side forests than east-side forests (Table 7). Under the Comprehensive treatment, timber product values exceeded treatment costs on 61 percent of the west-side acres, compared to only 40 percent east of the Divide.

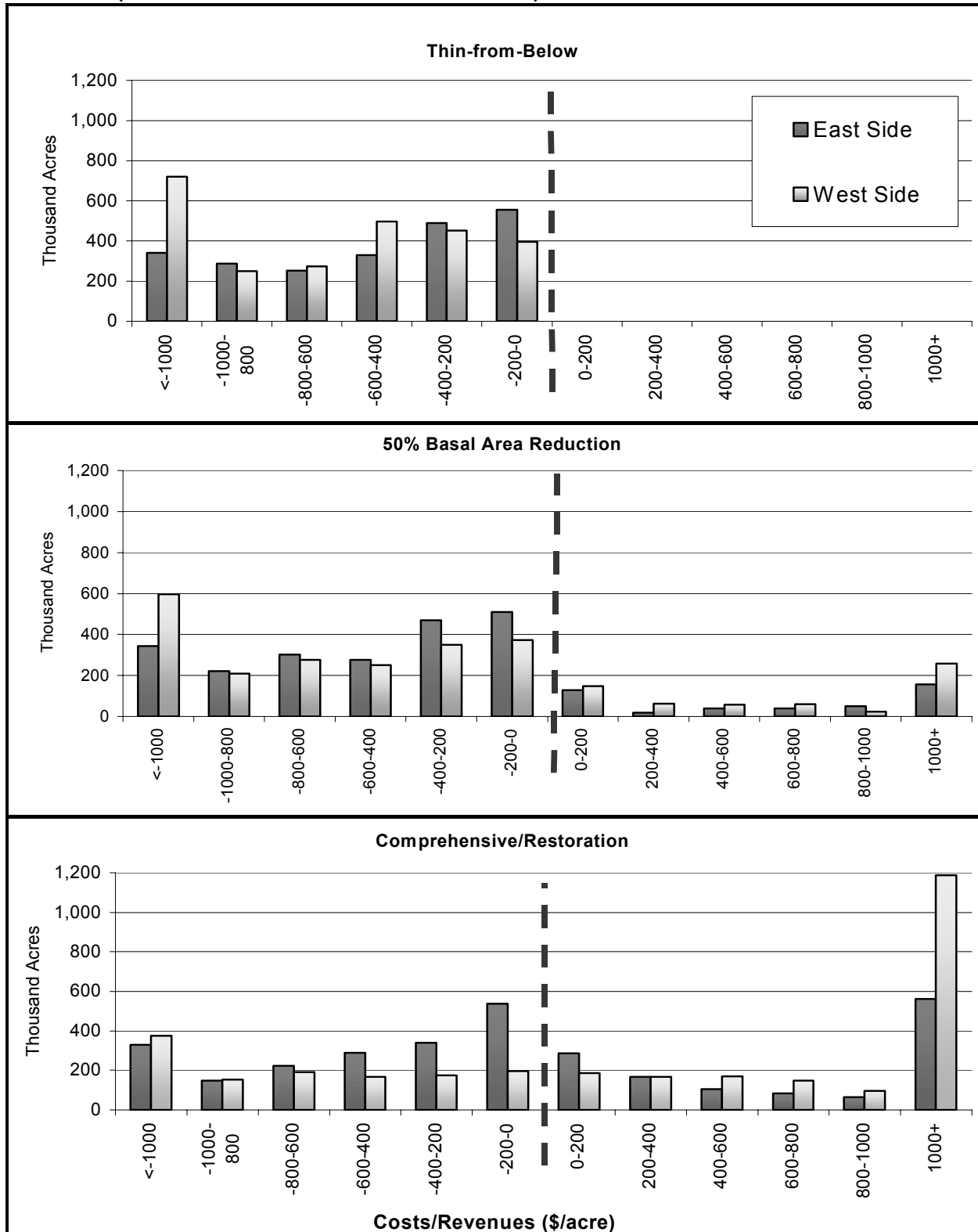
Figure 5. Distribution of acres by net revenue and hazard reduction treatment for high/moderate hazard conditions in PP, DF, and DLMC forest types (1997-1999 market conditions).



Because stands in western Montana also supported a greater number of small trees with little or no product value, the average cost of applying the Thin-from-Below treatment was \$162 per acre higher (-\$740 vs. -\$578) in west- versus east-side forests (Figure 6; Table 7). Conversely, there was little difference in costs (-\$304 vs. -\$286 per acre) west and east of the Continental Divide for the 50% Basal Area Removal treatment (Table 7).

Several market conditions were evaluated, and different market assumptions resulted in different costs and revenues associated with the alternative treatment prescriptions. However, fundamental differences among treatments did not change under the various market scenarios. For example, inclusion of a roundwood pulpwood market - which provides an improved outlet for smaller material - improved the financial aspect of all of the treatments. Under the pulpwood scenario, the Thin-from-Below and 50% Basal Area Removal treatments required smaller (though still substantial) expenditures to implement, while the Comprehensive prescription yielded even greater positive revenues.

Figure 6. Distribution of acres by net revenue and hazard reduction treatment for high/moderate hazard conditions in PP, DF, and DLMC forest types, west and east of the Continental Divide (1997-1999 market conditions).



DISCUSSION

It is critical that managers carefully review options before applying hazard reduction treatments. Just calling a treatment "hazard reduction" does not make it so. For example, applying the Thin-from-Below prescription to high/moderate hazard PP/DF/DLMC stands (i.e., short-interval, fire-adapted ecosystems) has little effect on lowering crown fire hazard. In the Dense, Two- and Multi-storied stands in western Montana where fire hazard is greatest, average Crowning Index was only 2-3 mph higher after receiving the Thin-from-Below treatment than before. These results underscore the importance of evaluating pre- and post-treatment conditions (stand tables) for Crowning Index during the process of prescription development.

Our results demonstrate that a Comprehensive hazard reduction approach that focuses on restoring sustainable structure (and ultimately ecological function) in short-interval, fire-adapted forests is dramatically superior to other commonly recommended treatments in reducing fire hazard, as well as in cost of implementation. A comprehensive, ecologically-based approach identifies a desired future range of conditions (of which low fire hazard is a part), evaluates the existing stand, and reserves trees in the sizes, numbers, species, and juxtaposition that make the most progress toward these desired conditions. Put another way, trees that do not contribute to this objective are removed from the stand - they are a by-product of the ecologically-based treatment. In contrast, other prescriptions generally start with the premise that fire hazard is essentially a one-dimensional, small-tree problem, and therefore prescribe the removal of variable amounts of small trees to address it. However, our evaluation of crown fire hazard following treatment shows that these small-tree removal prescriptions do not achieve their stated objective. While removing small trees is a necessary part of any effort to reduce hazard, this analysis clearly shows that it is not sufficient.

The Comprehensive treatment, with multiple ecologically-based objectives, moves 90 percent of treated acres into a low-hazard condition following treatment. In addition, removing late-successional species and reducing density sufficiently to induce seral species regeneration (and enhance sustainability) commonly require cutting some medium-sized and larger trees with commercial value, which on average yield enough revenue to cover treatment costs. Furthermore, the hazard reduction effects are longer lasting, with over 70 percent of treated stands remaining in a low-hazard condition 30 years after treatment.

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Appendix 1a. Acres by region, forest type, density, and structure.

State of Montana

Structure/Forest Type	PP	DF	WL	LP	Dry LMC	Moist LMC	UMC	Spruce/Fir	Timberline	Other	TOTAL
No Structure	27,468	17,466	NA	NA	NA	12,573	NA	6,381	11,691	11,333	86,912
Scattered	487,363	454,678	124,611	259,645	28,832	85,720	29,873	318,471	71,851	70,499	1,931,543
One-story	263,984	524,393	268,847	2,320,671	35,673	125,874	95,546	279,396	62,040	111,386	4,087,810
Two-story	1,120,792	1,389,267	121,088	1,513,052	86,486	319,839	198,750	749,459	171,044	269,536	5,939,313
Multi-storied	941,578	3,790,828	19,091	250,693	114,697	830,999	369,267	2,514,152	271,631	311,712	9,414,648
Total	2,841,185	6,176,632	533,637	4,344,061	265,688	1,375,005	693,436	3,867,859	588,257	774,466	21,460,226

Density/Forest Type	PP	DF	WL	LP	Dry LMC	Moist LMC	UMC	Spruce/Fir	Timberline	Other	TOTAL
Low	1,114,917	2,152,151	191,595	1,415,442	74,869	546,487	220,753	1,290,458	287,521	259,343	7,553,536
Moderate	861,810	1,925,413	165,900	1,412,681	105,976	461,943	241,253	1,310,343	113,838	267,809	6,866,966
High	864,458	2,099,068	176,142	1,515,938	84,843	366,575	231,430	1,267,058	186,898	247,314	7,039,724
Total	2,841,185	6,176,632	533,637	4,344,061	265,688	1,375,005	693,436	3,867,859	588,257	774,466	21,460,226

West of the Divide

Structure/Forest Type	PP	DF	WL	LP	Dry LMC	Moist LMC	UMC	Spruce/Fir	Timberline	Other	TOTAL
No Structure	5,808	17,466	NA	NA	NA	12,573	NA	6,381	NA	NA	42,228
Scattered	96,518	281,948	124,611	125,334	19,170	61,042	24,710	197,828	24,393	NA	955,554
One-story	49,989	293,841	268,847	925,992	21,349	114,565	56,483	168,494	23,305	NA	1,922,865
Two-story	222,303	765,746	121,088	743,312	57,895	271,452	140,402	412,516	77,643	20,374	2,832,731
Multi-storied	257,203	2,244,050	19,091	86,745	95,273	709,524	257,625	1,463,165	90,455	42,509	5,265,640
Total	631,821	3,603,051	533,637	1,881,383	193,687	1,169,156	479,220	2,248,384	215,796	62,883	11,019,018

Density/Forest Type	PP	DF	WL	LP	Dry LMC	Moist LMC	UMC	Spruce/Fir	Timberline	Other	TOTAL
Low	225,294	1,279,848	191,595	583,363	59,708	414,179	145,940	788,008	125,168	20,218	3,833,321
Moderate	210,939	1,187,226	165,900	635,562	74,797	419,427	172,054	740,294	55,477	17,649	3,679,325
High	195,588	1,135,977	176,142	662,458	59,182	335,550	161,226	720,082	35,151	25,016	3,506,372
Total	631,821	3,603,051	533,637	1,881,383	193,687	1,169,156	479,220	2,248,384	215,796	62,883	11,019,018

East of the Divide

Structure/Forest Type	PP	DF	WL	LP	Dry LMC	Moist LMC	UMC	Spruce/Fir	Timberline	Other	TOTAL
No Structure	21,660	NA	NA	NA	NA	NA	NA	NA	11,691	11,333	44,684
Scattered	390,845	172,730	NA	134,311	9,662	24,678	5,163	120,643	47,458	70,499	975,989
One-story	213,995	230,552	NA	1,394,679	14,324	11,309	39,063	110,902	38,735	111,386	2,164,945
Two-story	898,489	623,521	NA	769,740	28,591	48,387	58,348	336,943	93,401	249,162	3,106,582
Multi-storied	684,375	1,546,778	NA	163,948	19,424	121,475	111,642	1,050,987	181,176	269,203	4,149,008
Total	2,209,364	2,573,581	NA	2,462,678	72,001	205,849	214,216	1,619,475	372,461	711,583	10,441,208

Density/Forest Type	PP	DF	WL	LP	Dry LMC	Moist LMC	UMC	Spruce/Fir	Timberline	Other	TOTAL
Low	889,623	872,303	NA	832,079	15,161	132,308	74,813	502,450	162,353	239,125	3,720,215
Moderate	650,871	738,187	NA	777,119	31,179	42,516	69,199	570,049	58,361	250,160	3,187,641
High	668,870	963,091	NA	853,480	25,661	31,025	70,204	546,976	151,747	222,298	3,533,352
Total	2,209,364	2,573,581	NA	2,462,678	72,001	205,849	214,216	1,619,475	372,461	711,583	10,441,208

LMC = Lower mixed conifer, UMC = Upper mixed conifer.

NA = no clusters recorded.

Appendix 1b. Acres by ownership, forest type, density, and structure in the state of Montana.

FEDERAL

Structure/Forest Type	PP	DF	WL	LP	Dry LMC	Moist LMC	UMC	Spruce/Fir	Timberline	Other	TOTAL
No Structure	10,128	17,466	0	0	0	12,573	0	6,381	11,691	11,333	69,572
Scattered	211,936	269,181	90,487	167,167	15,937	61,645	12,847	286,080	71,851	40,370	1,227,501
One	53,899	335,708	174,641	1,975,345	0	74,386	82,821	238,250	62,040	22,079	3,019,169
Two	318,209	885,940	77,499	1,268,220	48,765	216,292	172,518	657,836	171,044	77,461	3,893,784
Multi-storied	353,460	2,397,635	12,573	203,301	62,325	548,041	325,424	2,305,797	261,276	126,258	6,596,090
Total	947,632	3,905,930	355,200	3,614,033	127,027	912,937	593,610	3,494,344	577,902	277,501	14,806,116

Density/Forest Type	PP	DF	WL	LP	Dry LMC	Moist LMC	UMC	Spruce/Fir	Timberline	Other	TOTAL
Low	395,746	1,383,147	140,286	1,095,069	22,318	388,578	187,389	1,182,900	287,521	113,433	5,196,387
Moderate	277,114	1,283,409	118,485	1,277,784	66,629	364,277	230,175	1,229,864	107,643	81,389	5,036,769
High	274,772	1,239,374	96,429	1,241,180	38,080	160,082	176,046	1,081,580	182,738	82,679	4,572,960
Total	947,632	3,905,930	355,200	3,614,033	127,027	912,937	593,610	3,494,344	577,902	277,501	14,806,116

PRIVATE

Structure/Forest Type	PP	DF	WL	LP	Dry LMC	Moist LMC	UMC	Spruce/Fir	Timberline	Other	TOTAL
No Structure	17,340	0	0	0	0	0	0	0	0	0	17,340
Scattered	235,977	156,895	26,364	79,578	12,895	18,038	17,026	26,354	0	18,172	591,299
One	184,142	169,071	76,341	269,914	26,836	39,205	11,002	26,079	0	61,539	864,129
Two	652,159	442,920	30,358	192,714	28,217	82,259	22,786	61,555	0	163,416	1,676,384
Multi-storied	432,938	1,072,575	0	40,940	33,419	206,791	30,919	137,994	4,160	153,406	2,113,142
Total	1,522,556	1,841,461	133,063	583,146	101,367	346,293	81,733	251,982	4,160	396,533	5,262,294

Density/Forest Type	PP	DF	WL	LP	Dry LMC	Moist LMC	UMC	Spruce/Fir	Timberline	Other	TOTAL
Low	593,320	657,129	41,826	275,418	45,753	130,839	28,195	86,164	0	101,632	1,960,276
Moderate	482,076	549,850	39,895	97,210	31,913	88,735	5,362	50,318	0	158,681	1,504,040
High	447,160	634,482	51,342	210,518	23,701	126,719	48,176	115,500	4,160	136,220	1,797,978
Total	1,522,556	1,841,461	133,063	583,146	101,367	346,293	81,733	251,982	4,160	396,533	5,262,294

OTHER

Structure/Forest Type	PP	DF	WL	LP	Dry LMC	Moist LMC	UMC	Spruce/Fir	Timberline	Other	TOTAL
No Structure	0	0	0	0	0	0	0	0	0	0	0
Scattered	39,450	28,602	7,760	12,900	0	6,037	0	6,037	0	11,957	112,743
One-story	25,943	19,614	17,865	75,412	8,837	12,283	1,723	15,067	0	27,768	204,512
Two-story	150,424	60,407	13,231	52,118	9,504	21,288	3,446	30,068	0	28,659	369,145
Multi-storied	155,180	320,618	6,518	6,452	18,953	76,167	12,924	70,361	6,195	32,048	705,416
Total	370,997	429,241	45,374	146,882	37,294	115,775	18,093	121,533	6,195	100,432	1,391,816

Density/Forest Type	PP	DF	WL	LP	Dry LMC	Moist LMC	UMC	Spruce/Fir	Timberline	Other	TOTAL
Low	125,851	111,875	9,483	44,955	6,798	27,070	5,169	21,394	0	44,278	396,873
Moderate	102,620	92,154	7,520	37,687	7,434	8,931	5,716	30,161	6,195	27,739	326,157
High	142,526	225,212	28,371	64,240	23,062	79,774	7,208	69,978	0	28,415	668,786
Total	370,997	429,241	45,374	146,882	37,294	115,775	18,093	121,533	6,195	100,432	1,391,816

LMC = Lower mixed conifer, UMC = Upper mixed conifer.

NA = no clusters recorded.

Appendix 1c. Acres by ownership, forest type, density, and structure for Montana, west of the Divide.

FEDERAL

Structure/Forest Type	PP	DF	WL	LP	Dry LMC	Moist LMC	UMC	Spruce/Fir	Timberline	Other	TOTAL
No Structure	5,808	17,466	0	0	0	12,573	0	6,381	0	0	42,228
Scattered	31,073	175,659	90,487	68,806	6,275	36,967	12,847	170,600	24,393	0	617,107
One	18,362	165,820	174,641	750,190	0	74,386	49,257	158,011	23,305	0	1,413,972
Two	89,707	436,210	77,499	587,670	36,479	179,275	123,555	359,458	77,643	6,277	1,973,773
Multi-storied	93,701	1,333,566	12,573	80,293	49,455	432,282	225,122	1,362,164	86,295	0	3,675,451
Total	238,651	2,128,721	355,200	1,486,959	92,209	735,483	410,781	2,056,614	211,636	6,277	7,722,531

Density/Forest Type	PP	DF	WL	LP	Dry LMC	Moist LMC	UMC	Spruce/Fir	Timberline	Other	TOTAL
Low	95,437	814,416	140,286	462,339	12,656	278,949	123,238	736,569	125,168	6,277	2,795,335
Moderate	99,844	779,985	118,485	556,166	60,580	321,761	166,692	709,248	55,477	0	2,868,238
High	43,370	534,320	96,429	468,454	18,973	134,773	120,851	610,797	30,991	0	2,058,958
Total	238,651	2,128,721	355,200	1,486,959	92,209	735,483	410,781	2,056,614	211,636	6,277	7,722,531

PRIVATE

Structure/Forest Type	PP	DF	WL	LP	Dry LMC	Moist LMC	UMC	Spruce/Fir	Timberline	Other	TOTAL
No Structure	0	0	0	0	0	0	0	0	0	0	0
Scattered	60,693	91,628	26,364	43,628	12,895	18,038	11,863	21,191	0	0	286,300
One	17,402	123,081	76,341	141,897	12,512	27,896	5,503	8,760	0	0	413,392
Two	89,698	282,661	30,358	115,435	11,912	70,889	13,401	41,759	0	13,941	670,054
Multi-storied	105,136	641,207	0	0	26,865	206,791	25,295	47,788	4,160	36,232	1,093,474
Total	272,929	1,138,577	133,063	300,960	64,184	323,614	56,062	119,498	4,160	50,173	2,463,220

Density/Forest Type	PP	DF	WL	LP	Dry LMC	Moist LMC	UMC	Spruce/Fir	Timberline	Other	TOTAL
Low	94,023	388,367	41,826	100,511	40,254	108,160	17,533	41,956	0	13,941	846,571
Moderate	84,118	328,619	39,895	53,110	6,783	88,735	5,362	19,654	0	11,216	637,492
High	94,788	421,591	51,342	40,254	17,147	126,719	33,167	57,888	4,160	25,016	872,072
Total	272,929	1,138,577	133,063	193,875	64,184	323,614	56,062	119,498	4,160	50,173	2,356,135

OTHER

Structure/Forest Type	PP	DF	WL	LP	Dry LMC	Moist LMC	UMC	Spruce/Fir	Timberline	Other	TOTAL
No Structure	0	0	0	0	0	0	0	0	0	0	0
Scattered	4,752	14,661	7,760	12,900	0	6,037	0	6,037	0	0	52,147
One-story	14,225	4,940	17,865	33,905	8,837	12,283	1,723	1,723	0	0	95,501
Two-story	42,898	46,875	13,231	40,207	9,504	21,288	3,446	11,299	0	6,433	195,181
Multi-storied	58,366	269,277	6,518	6,452	18,953	70,451	7,208	53,213	0	0	490,438
Total	120,241	335,753	45,374	93,464	37,294	110,059	12,377	72,272	0	6,433	833,267

Density/Forest Type	PP	DF	WL	LP	Dry LMC	Moist LMC	UMC	Spruce/Fir	Timberline	Other	TOTAL
Low	35,834	77,065	9,483	20,513	6,798	27,070	5,169	9,483	0	0	191,415
Moderate	26,977	78,622	7,520	26,286	7,434	8,931	0	11,392	0	6,433	173,595
High	57,430	180,066	28,371	46,665	23,062	74,058	7,208	51,397	0	0	468,257
Total	120,241	335,753	45,374	93,464	37,294	110,059	12,377	72,272	0	6,433	833,267

LMC = Lower mixed conifer, UMC = Upper mixed conifer.

NA = no clusters recorded.

Appendix 1d. Acres by ownership, forest type, density, and structure for Montana, east of the Divide.

FEDERAL

Structure/Forest Type	PP	DF	WL	LP	Dry LMC	Moist LMC	UMC	Spruce/Fir	Timberline	Other	TOTAL
No Structure	4,320	0	0	0	0	0	0	0	11,691	11,333	27,344
Scattered	180,863	93,522	0	98,361	9,662	24,678	0	115,480	47,458	40,370	610,394
One	35,537	169,888	0	1,225,155	0	0	33,564	80,239	38,735	22,079	1,605,197
Two	228,502	449,730	0	680,550	12,286	37,017	48,963	298,378	93,401	77,461	1,926,288
Multi-storied	259,759	1,064,069	0	123,008	12,870	115,759	100,302	943,633	174,981	119,981	2,914,362
Total	708,981	1,777,209	0	2,127,074	34,818	177,454	182,829	1,437,730	366,266	271,224	7,083,585

Density/Forest Type	PP	DF	WL	LP	Dry LMC	Moist LMC	UMC	Spruce/Fir	Timberline	Other	TOTAL
Low	300,309	568,731	0	632,730	9,662	109,629	64,151	446,331	162,353	107,156	2,401,052
Moderate	177,270	503,424	0	721,618	6,049	42,516	63,483	520,616	52,166	81,389	2,168,531
High	231,402	705,054	0	772,726	19,107	25,309	55,195	470,783	151,747	82,679	2,514,002
Total	708,981	1,777,209	0	2,127,074	34,818	177,454	182,829	1,437,730	366,266	271,224	7,083,585

PRIVATE

Structure/Forest Type	PP	DF	WL	LP	Dry LMC	Moist LMC	UMC	Spruce/Fir	Timberline	Other	TOTAL
No Structure	17,340	0	0	0	0	0	0	0	0	0	17,340
Scattered	175,284	65,267	0	35,950	0	0	5,163	5,163	0	18,172	304,999
One	166,740	45,990	0	128,017	14,324	11,309	5,499	17,319	0	61,539	450,737
Two	562,461	160,259	0	77,279	16,305	11,370	9,385	19,796	0	149,475	1,006,330
Multi-storied	327,802	431,368	0	40,940	6,554	0	5,624	90,206	0	117,174	1,019,668
Total	1,249,627	702,884	0	282,186	37,183	22,679	25,671	132,484	0	346,360	2,799,074

Density/Forest Type	PP	DF	WL	LP	Dry LMC	Moist LMC	UMC	Spruce/Fir	Timberline	Other	TOTAL
Low	499,297	268,762	0	174,907	5,499	22,679	10,662	44,208	0	87,691	1,113,705
Moderate	397,958	221,231	0	44,100	25,130	0	0	30,664	0	147,465	866,548
High	352,372	212,891	0	63,179	6,554	0	15,009	57,612	0	111,204	818,821
Total	1,249,627	702,884	0	282,186	37,183	22,679	25,671	132,484	0	346,360	2,799,074

OTHER

Structure/Forest Type	PP	DF	WL	LP	Dry LMC	Moist LMC	UMC	Spruce/Fir	Timberline	Other	TOTAL
No Structure	0	0	0	0	0	0	0	0	0	0	0
Scattered	34,698	13,941	0	0	0	0	0	0	0	11,957	60,596
One-story	11,718	14,674	0	41,507	0	0	0	13,344	0	27,768	109,011
Two-story	107,526	13,532	0	11,911	0	0	0	18,769	0	22,226	173,964
Multi-storied	96,814	51,341	0	0	0	5,716	5,716	17,148	6,195	32,048	214,978
Total	250,756	93,488	0	53,418	0	5,716	5,716	49,261	6,195	93,999	558,549

Density/Forest Type	PP	DF	WL	LP	Dry LMC	Moist LMC	UMC	Spruce/Fir	Timberline	Other	TOTAL
Low	90,017	34,810	0	24,442	0	0	0	11,911	0	44,278	205,458
Moderate	75,643	13,532	0	11,401	0	0	5,716	18,769	6,195	21,306	152,562
High	85,096	45,146	0	17,575	0	5,716	0	18,581	0	28,415	200,529
Total	250,756	93,488	0	53,418	0	5,716	5,716	49,261	6,195	93,999	558,549

LMC = Lower mixed conifer, UMC = Upper mixed conifer.

NA = no clusters recorded.

Appendix 2. Acres by region, ownership, density, and structure.

State of Montana

Structure

	Federal	Private	Other	Total
No Structure	69,572	17,340	0	86,912
Scattered	1,227,501	591,299	112,743	1,931,543
One-story	3,019,169	864,129	204,512	4,087,810
Two-story	3,893,784	1,676,384	369,145	5,939,313
Multi-storied	6,596,090	2,113,142	705,416	9,414,648
All	14,806,116	5,262,294	1,391,816	21,460,226

Density

	Federal	Private	Other	Total
Low	5,196,387	1,960,276	396,873	7,553,536
Moderate	5,036,769	1,504,040	326,157	6,866,966
High	4,572,960	1,797,978	668,786	7,039,724
All	14,806,116	5,262,294	1,391,816	21,460,226

Structure/Density

	Federal	Private	Other	Total
Scattered, low	1,227,501	591,299	112,743	1,931,543
Scattered, moderate	0	0	0	0
Scattered, high	0	0	0	0
One-story, low	1,367,701	483,087	104,217	1,955,005
One-story, moderate	913,055	227,531	29,126	1,169,712
One-story, high	738,413	153,511	71,169	963,093
Two-story, low	1,600,834	621,928	119,442	2,342,204
Two-story, moderate	1,315,027	624,174	139,864	2,079,065
Two-story, high	977,923	430,282	109,839	1,518,044
Multi-storied, low	930,779	246,622	60,471	1,237,872
Multi-storied, moderate	2,808,687	652,335	157,167	3,618,189
Multi-storied, high	2,856,624	1,214,185	487,778	4,558,587
All	14,736,544	5,244,954	1,391,816	21,373,314

West of the Divide

Structure

	Federal	Private	Other	Total
No Structure	42,228	0	0	42,228
Scattered	617,107	286,300	52,147	955,554
One-story	1,413,972	413,392	95,501	1,922,865
Two-story	1,967,496	670,054	195,181	2,832,731
Multi-storied	3,681,728	1,093,474	490,438	5,265,640
All	7,722,531	2,463,220	833,267	11,019,018

Density

	Federal	Private	Other	Total
Low	2,795,335	846,571	191,415	3,833,321
Moderate	2,868,238	637,492	173,595	3,679,325
High	2,058,958	979,157	468,257	3,506,372
All	7,722,531	2,463,220	833,267	11,019,018

Structure/Density

	Federal	Private	Other	Total
Scattered, low	617,107	286,300	52,147	955,554
Scattered, moderate	0	0	0	0
Scattered, high	0	0	0	0
One-story, low	715,889	214,949	37,190	968,028
One-story, moderate	399,388	95,788	23,441	518,617
One-story, high	298,695	102,655	34,870	436,220
Two-story, low	872,836	221,511	65,236	1,159,583
Two-story, moderate	704,505	204,921	56,830	966,256
Two-story, high	390,155	243,622	73,115	706,892
Multi-storied, low	547,275	123,811	36,842	707,928
Multi-storied, moderate	1,764,345	336,783	93,324	2,194,452
Multi-storied, high	1,370,108	632,880	360,272	2,363,260
All	7,680,303	2,463,220	833,267	10,976,790

East of the Divide

Structure

	Federal	Private	Other	Total
No Structure	27,344	17,340	0	44,684
Scattered	610,394	304,999	60,596	975,989
One-story	1,605,197	450,737	109,011	2,164,945
Two-story	1,926,288	1,006,330	173,964	3,106,582
Multi-storied	2,914,362	1,019,668	214,978	4,149,008
All	7,083,585	2,799,074	558,549	10,441,208

Density

	Federal	Private	Other	Total
Low	2,401,052	1,113,705	205,458	3,720,215
Moderate	2,168,531	866,548	152,562	3,187,641
High	2,514,002	818,821	200,529	3,533,352
All	7,083,585	2,799,074	558,549	10,441,208

Structure/Density

	Federal	Private	Other	Total
Scattered, low	610,394	304,999	60,596	975,989
Scattered, moderate	0	0	0	0
Scattered, high	0	0	0	0
One-story, low	651,812	268,138	67,027	986,977
One-story, moderate	513,667	131,743	5,685	651,095
One-story, high	439,718	50,856	36,299	526,873
Two-story, low	727,998	400,417	54,206	1,182,621
Two-story, moderate	610,522	419,253	83,034	1,112,809
Two-story, high	587,768	186,660	36,724	811,152
Multi-storied, low	383,504	122,811	23,629	529,944
Multi-storied, moderate	1,044,342	315,552	63,843	1,423,737
Multi-storied, high	1,486,516	581,305	127,506	2,195,327
All	7,056,241	2,781,734	558,549	10,396,524

Appendix 3. Basal area ranges for Low, Moderate, and High density classes, by forest type and geographic region within Montana.

West of the Continental Divide				East of the Continental Divide			
Forest Type	Basal Area (ft ² /ac)			Forest Type	Basal Area (ft ² /ac)		
	Low	Moderate	High		Low	Moderate	High
PP	<50	50-100	>100	PP	<40	40-75	>75
DF	<90	90-150	>150	DF	<80	80-130	>130
DLMC	<80	80-130	>130	DLMC	<60	60-130	>130
WL	<50	50-125	>125	WL	N/A	N/A	N/A
LP	<100	100-160	>160	LP	<110	110-160	>160
MLMC	<130	130-210	>210	MLMC	<130	130-210	>210
UMC	<110	110-160	>160	UMC	<100	100-160	>160
S/F	<85	85-145	>145	S/F	<100	100-160	>160
TL	<50	50-80	>80	TL	<60	60-140	>140

Appendix 4. Average Crowning Index by region, ownership, density, and structure.

State of Montana

Structure

	Federal	Private	Other	All
No Structure	51	63	-	53
Scattered	69	66	71	68
One-story	32	40	38	34
Two-story	30	37	34	32
Multi-storied	25	25	24	25
All	30	35	31	31

Density

	Federal	Private	Other	All
Low	45	52	54	47
Moderate	27	34	29	29
High	20	21	22	21
All	30	35	31	31

Structure/Density

	Federal	Private	Other	All
Scattered, low	69	66	71	68
Scattered, moderate	-	-	-	-
Scattered, high	-	-	-	-
One-story, low	42	48	54	45
One-story, moderate	27	37	25	29
One-story, high	20	19	28	20
Two-story, low	36	48	48	40
Two-story, moderate	28	36	30	31
Two-story, high	21	24	24	22
Multi-storied, low	33	33	41	33
Multi-storied, moderate	27	32	29	28
Multi-storied, high	20	20	21	20
All	30	35	31	31

West of the Divide

Structure

	Federal	Private	Other	All
No Structure	67	-	-	67
Scattered	75	61	75	71
One-story	38	39	39	38
Two-story	33	34	31	33
Multi-storied	28	24	24	26
All	34	33	29	31

Density

	Federal	Private	Other	All
Low	49	51	54	50
Moderate	29	33	28	30
High	23	20	22	22
All	34	33	29	31

Structure/Density

	Federal	Private	Other	All
Scattered, low	75	61	75	71
Scattered, moderate	-	-	-	-
Scattered, high	-	-	-	-
One-story, low	48	46	64	49
One-story, moderate	31	41	25	32
One-story, high	22	21	29	23
Two-story, low	39	51	43	41
Two-story, moderate	30	32	28	30
Two-story, high	25	21	22	23
Multi-storied, low	36	34	41	36
Multi-storied, moderate	29	31	29	29
Multi-storied, high	23	19	21	22
All	34	33	29	31

East of the Divide

Structure

	Federal	Private	Other	All
No Structure	29	63	-	41
Scattered	63	70	65	65
One-story	27	41	36	31
Two-story	26	39	41	31
Multi-storied	21	26	27	23
All	26	37	37	29

Density

	Federal	Private	Other	All
Low	41	52	53	45
Moderate	25	36	32	28
High	18	22	24	19
All	26	37	37	29

Structure/Density

	Federal	Private	Other	All
Scattered, low	63	70	65	65
Scattered, moderate	-	-	-	-
Scattered, high	-	-	-	-
One-story, low	37	49	44	41
One-story, moderate	24	35	23	26
One-story, high	18	15	25	18
Two-story, low	33	46	58	38
Two-story, moderate	26	38	34	31
Two-story, high	19	28	31	21
Multi-storied, low	27	33	40	29
Multi-storied, moderate	24	32	31	27
Multi-storied, high	18	21	22	19
All	26	37	37	29

Appendix 5a. Average Crowning Index by region, forest type, density, and structure.

State of Montana

Structure/Forest Type	PP	DF	WL	LP	Dry LMC	Moist LMC	UMC	Spruce/Fir	Timberline	Other	All
No Structure	62	63	NA	NA	NA	79	NA	42	25	24	53
Scattered	61	74	107	66	61	61	62	63	63	64	68
One-story	57	51	48	25	33	45	31	34	27	45	34
Two-story	40	34	37	24	33	38	31	27	24	41	32
Multi-storied	30	25	32	27	29	25	27	22	17	25	25
All	42	33	57	28	34	32	30	27	25	37	31

Density/Forest Type	PP	DF	WL	LP	Dry LMC	Moist LMC	UMC	Spruce/Fir	Timberline	Other	All
Low	58	50	94	40	50	45	39	39	36	50	47
Moderate	38	28	47	25	34	28	30	24	18	39	29
High	27	20	32	19	23	21	22	19	14	20	21
All	42	33	57	28	34	32	30	27	25	37	31

West of the Divide

Structure/Forest Type	PP	DF	WL	LP	Dry LMC	Moist LMC	UMC	Spruce/Fir	Timberline	Other	All
No Structure	76	63	NA	NA	NA	79	NA	42	NA	NA	67
Scattered	56	78	107	49	72	50	53	72	56	NA	71
One-story	82	55	48	27	38	45	31	35	37	NA	38
Two-story	43	37	37	24	38	39	33	29	28	33	33
Multi-storied	35	26	32	27	31	25	30	24	19	33	26
All	45	35	57	28	37	32	32	30	29	33	33

Density/Forest Type	PP	DF	WL	LP	Dry LMC	Moist LMC	UMC	Spruce/Fir	Timberline	Other	All
Low	62	53	94	39	51	46	41	43	36	43	50
Moderate	46	29	47	24	38	29	32	26	22	33	30
High	29	21	32	20	25	22	24	20	14	26	22
All	45	35	57	28	37	32	32	30	29	33	33

East of the Divide

Structure/Forest Type	PP	DF	WL	LP	Dry LMC	Moist LMC	UMC	Spruce/Fir	Timberline	Other	All
No Structure	58	NA	NA	NA	NA	NA	NA	NA	25	24	41
Scattered	62	67	NA	85	44	89	101	48	67	64	65
One-story	50	47	NA	24	16	49	31	32	21	45	31
Two-story	40	31	NA	24	24	34	23	24	20	42	31
Multi-storied	28	23	NA	27	27	22	22	19	16	24	23
All	41	30	NA	27	25	35	26	23	24	37	29

Density/Forest Type	PP	DF	WL	LP	Dry LMC	Moist LMC	UMC	Spruce/Fir	Timberline	Other	All
Low	57	45	NA	40	44	44	35	32	36	51	45
Moderate	36	27	NA	25	19	18	26	22	15	40	28
High	26	19	NA	18	17	19	17	17	14	20	19
All	41	30	NA	27	25	35	26	23	24	37	29

LMC = Lower mixed conifer, UMC = Upper mixed conifer.

NA = no clusters recorded.

Appendix 5b. Average Crowning Index by ownership, forest type, density, and structure for Montana.

FEDERAL

Structure/Forest Type	PP	DF	WL	LP	Dry LMC	Moist LMC	UMC	Spruce/Fir	Timberline	Other	All
No Structure	60	64	NA	NA	NA	79	NA	42	25	24	51
Scattered	58	68	122	67	68	68	52	65	63	73	69
One	68	54	52	25	NA	55	30	34	27	39	32
Two	40	33	44	24	35	37	32	27	24	25	29
Multi-storied	31	26	30	29	31	27	27	23	17	15	25
All	43	33	67	27	38	35	29	27	26	29	30

Density/Forest Type	PP	DF	WL	LP	Dry LMC	Moist LMC	UMC	Spruce/Fir	Timberline	Other	All
Low	56	49	106	38	59	45	36	39	36	47	45
Moderate	40	29	45	25	39	29	30	24	18	21	27
High	27	20	37	19	21	24	22	19	15	12	20
All	43	33	67	27	38	35	29	27	26	29	30

PRIVATE

Structure/Forest Type	PP	DF	WL	LP	Dry LMC	Moist LMC	UMC	Spruce/Fir	Timberline	Other	All
No Structure	63	NA	NA	NA	NA	NA	NA	NA	NA	NA	63
Scattered	63	77	73	63	50	47	69	52	NA	61	66
One	51	42	48	29	34	35	29	32	NA	52	40
Two	39	36	29	27	32	45	21	29	NA	50	37
Multi-storied	28	24	NA	22	27	24	23	21	9	32	25
All	41	33	49	32	33	32	34	27	9	43	35

Density/Forest Type	PP	DF	WL	LP	Dry LMC	Moist LMC	UMC	Spruce/Fir	Timberline	Other	All
Low	57	50	63	44	45	46	55	43	NA	61	52
Moderate	38	29	63	30	22	25	28	25	NA	49	34
High	25	19	26	18	23	20	20	17	9	25	21
All	41	33	49	32	33	32	34	27	9	43	35

OTHER

Structure/Forest Type	PP	DF	WL	LP	Dry LMC	Moist LMC	UMC	Spruce/Fir	Timberline	Other	All
No Structure	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Scattered	63	104	72	72	0	30	NA	23	NA	38	70
One-story	72	69	32	26	32	33	50	34	NA	36	38
Two-story	46	32	25	20	29	34	25	23	NA	43	34
Multi-storied	32	24	33	16	27	20	32	18	14	27	24
All	43	30	35	28	28	24	32	20	14	35	31

Density/Forest Type	PP	DF	WL	LP	Dry LMC	Moist LMC	UMC	Spruce/Fir	Timberline	Other	All
Low	68	54	70	50	44	43	46	30	NA	41	54
Moderate	38	27	29	18	29	25	32	24	14	41	29
High	30	21	27	19	26	20	22	17	NA	20	22
All	43	30	35	28	28	24	32	20	14	35	31

LMC = Lower mixed conifer, UMC = Upper mixed conifer.

NA = no clusters recorded.

Appendix 5c. Average Crowning Index by ownership, forest type, density, and structure for Montana, west of the Divide.

FEDERAL

Structure/Forest Type	PP	DF	WL	LP	Dry LMC	Moist LMC	UMC	Spruce/Fir	Timberline	Other	All
No Structure	76	64	NA	NA	NA	79	NA	42	NA	NA	67
Scattered	56	73	122	45	116	54	52	75	56	NA	75
One	107	60	52	27	NA	55	30	35	37	NA	38
Two	45	39	44	25	41	37	35	30	28	NA	33
Multi-storied	44	29	30	30	34	28	30	25	20	41	28
All	52	37	67	27	42	35	32	31	29	41	34

Density/Forest Type	PP	DF	WL	LP	Dry LMC	Moist LMC	UMC	Spruce/Fir	Timberline	Other	All
Low	61	53	106	37	75	46	39	43	36	41	49
Moderate	50	30	45	25	41	30	32	26	22	NA	29
High	36	23	37	21	25	25	25	21	15	NA	23
All	52	37	67	27	42	35	32	31	29	41	34

PRIVATE

Structure/Forest Type	PP	DF	WL	LP	Dry LMC	Moist LMC	UMC	Spruce/Fir	Timberline	Other	All
No Structure	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Scattered	60	78	73	38	50	47	53	54	NA	NA	61
One	59	45	48	29	43	28	17	50	NA	NA	39
Two	38	36	29	24	37	48	24	25	NA	35	34
Multi-storied	30	23	NA	NA	30	24	25	23	9	32	24
All	41	33	49	28	38	31	30	31	9	33	33

Density/Forest Type	PP	DF	WL	LP	Dry LMC	Moist LMC	UMC	Spruce/Fir	Timberline	Other	All
Low	57	53	63	40	45	48	45	47	NA	44	51
Moderate	44	29	63	30	31	25	28	23	NA	35	33
High	24	18	26	19	25	20	21	21	9	26	20
All	41	33	49	28	38	31	30	31	9	33	33

OTHER

Structure/Forest Type	PP	DF	WL	LP	Dry LMC	Moist LMC	UMC	Spruce/Fir	Timberline	Other	All
No Structure	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Scattered	27	117	72	72	NA	30	NA	23	NA	NA	75
One-story	79	79	32	27	32	33	50	29	NA	NA	39
Two-story	48	32	25	18	29	34	25	24	NA	28	31
Multi-storied	33	24	33	16	27	20	32	17	NA	NA	24
All	43	29	35	29	28	24	32	19	NA	28	29

Density/Forest Type	PP	DF	WL	LP	Dry LMC	Moist LMC	UMC	Spruce/Fir	Timberline	Other	All
Low	74	53	70	57	44	43	46	25	NA	NA	54
Moderate	41	27	29	17	29	25	NA	28	NA	28	28
High	32	20	27	19	26	20	22	17	NA	NA	22
All	43	29	35	29	28	24	32	19	NA	28	29

LMC = Lower mixed conifer, UMC = Upper mixed conifer.

NA = no clusters recorded.

Appendix 5d. Average Crowning Index by ownership, forest type, density, and structure for Montana, east of the Divide.

FEDERAL

Structure/Forest Type	PP	DF	WL	LP	Dry LMC	Moist LMC	UMC	Spruce/Fir	Timberline	Other	All
No Structure	44	NA	NA	NA	NA	NA	NA	NA	25	24	29
Scattered	58	60	NA	82	44	89	NA	48	67	73	63
One	48	49	NA	24	NA	NA	29	32	21	39	27
Two	38	28	NA	23	17	36	24	23	20	25	26
Multi-storied	27	23	NA	28	18	22	22	19	16	13	21
All	40	28	NA	26	26	35	23	23	24	29	26

Density/Forest Type	PP	DF	WL	LP	Dry LMC	Moist LMC	UMC	Spruce/Fir	Timberline	Other	All
Low	54	43	NA	39	44	45	28	31	36	47	41
Moderate	34	27	NA	25	22	18	25	22	15	21	25
High	25	18	NA	18	16	18	17	17	14	12	18
All	40	28	NA	26	26	35	23	23	24	29	26

PRIVATE

Structure/Forest Type	PP	DF	WL	LP	Dry LMC	Moist LMC	UMC	Spruce/Fir	Timberline	Other	All
No Structure	63	NA	NA	NA	NA	NA	NA	NA	NA	NA	63
Scattered	64	76	NA	98	NA	NA	101	48	NA	61	70
One	50	36	NA	28	16	49	41	23	NA	52	41
Two	39	37	NA	31	28	29	17	38	NA	51	39
Multi-storied	27	25	NA	22	17	0	16	20	NA	32	26
All	41	33	NA	36	23	39	43	24	NA	44	37

Density/Forest Type	PP	DF	WL	LP	Dry LMC	Moist LMC	UMC	Spruce/Fir	Timberline	Other	All
Low	57	46	NA	47	45	39	71	39	NA	64	52
Moderate	36	29	NA	29	18	NA	NA	27	NA	50	36
High	25	20	NA	15	17	NA	16	14	NA	25	22
All	41	33	NA	36	23	39	43	24	NA	44	37

OTHER

Structure/Forest Type	PP	DF	WL	LP	Dry LMC	Moist LMC	UMC	Spruce/Fir	Timberline	Other	All
No Structure	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Scattered	69	78	NA	NA	NA	NA	NA	NA	NA	38	64
One-story	57	59	NA	24	NA	NA	NA	37	NA	36	36
Two-story	44	32	NA	33	NA	NA	NA	22	NA	47	41
Multi-storied	31	23	NA	NA	NA	21	32	20	NA	27	27
All	43	37	NA	26	NA	21	32	25	NA	36	37

Density/Forest Type	PP	DF	WL	LP	Dry LMC	Moist LMC	UMC	Spruce/Fir	Timberline	Other	All
Low	65	60	NA	33	NA	NA	NA	37	NA	NA	53
Moderate	35	24	NA	22	NA	NA	32	20	NA	44	32
High	27	25	NA	19	NA	21	NA	22	NA	20	24
All	43	37	NA	26	NA	21	32	25	NA	36	37

LMC = Lower mixed conifer, UMC = Upper mixed conifer.

NA = no clusters recorded.

Appendix 6. Average Pre- and Post-treatment Crowning Indexes by region, ownership, density, and structure.
Treatment: Thin-from-Below to 9".

State of Montana

Structure

	Federal	Private	Other	All
No Structure	-/-	-/-	-/-	-/-
Scattered	-/-	-/-	-/-	-/-
One-story	33/38	34/41	29/40	33/40
Two-story	31/37	32/43	37/49	32/40
Multi-storied	26/31	23/35	25/42	25/32
All	27/33	26/37	27/33	27/34

Density

	Federal	Private	Other	All
Low	34/39	33/39	39/39	34/39
Moderate	30/35	31/43	32/42	30/38
High	22/28	21/33	23/30	22/30
All	27/33	26/37	27/33	27/34

Structure/Density

	Federal	Private	Other	All
Scattered, low	-/-	-/-	-/-	-/-
Scattered, moderate	-/-	-/-	-/-	-/-
Scattered, high	-/-	-/-	-/-	-/-
One-story, low	33/42	36/38	-/-	35/40
One-story, moderate	31/32	34/43	33/38	33/40
One-story, high	-/-	-/-	21/45	21/45
Two-story, low	38/39	33/37	38/38	36/38
Two-story, moderate	31/38	33/46	37/55	33/44
Two-story, high	24/32	29/39	36/44	27/36
Multi-storied, low	32/39	31/41	40/40	33/40
Multi-storied, moderate	29/34	29/41	29/33	29/35
Multi-storied, high	22/28	20/32	23/29	21/29
All	27/33	26/37	27/33	27/34

West of the Divide

Structure

	Federal	Private	Other	All
No Structure	-/-	-/-	-/-	-/-
Scattered	-/-	-/-	-/-	-/-
One-story	31/31	34/34	29/40	32/35
Two-story	35/38	30/35	36/44	33/38
Multi-storied	28/30	22/25	25/27	26/28
All	29/32	24/28	26/30	27/30

Density

	Federal	Private	Other	All
Low	37/37	33/33	39/39	36/36
Moderate	31/34	30/34	31/36	31/35
High	24/26	20/24	23/26	22/25
All	29/32	24/28	26/30	27/30

Structure/Density

	Federal	Private	Other	All
Scattered, low	-/-	-/-	-/-	-/-
Scattered, moderate	-/-	-/-	-/-	-/-
Scattered, high	-/-	-/-	-/-	-/-
One-story, low	-/-	40/40	-/-	40/40
One-story, moderate	31/31	25/25	33/38	29/31
One-story, high	-/-	-/-	21/45	21/45
Two-story, low	38/38	32/32	38/38	36/36
Two-story, moderate	35/39	34/43	36/50	35/42
Two-story, high	28/32	26/32	27/44	27/32
Multi-storied, low	35/35	31/32	40/40	36/36
Multi-storied, moderate	30/33	29/32	29/32	30/33
Multi-storied, high	24/25	19/22	23/25	22/24
All	29/32	24/28	26/30	27/30

East of the Divide

Structure

	Federal	Private	Other	All
No Structure	-/-	-/-	-/-	-/-
Scattered	-/-	-/-	-/-	-/-
One-story	33/41	35/45	-/-	34/43
Two-story	27/36	33/47	38/55	31/43
Multi-storied	23/33	24/45	23/49	23/37
All	24/34	28/46	29/51	26/39

Density

	Federal	Private	Other	All
Low	31/42	32/47	-/-	31/44
Moderate	27/36	32/48	36/58	30/42
High	21/30	23/44	26/48	22/36
All	24/34	28/46	29/51	26/39

Structure/Density

	Federal	Private	Other	All
Scattered, low	-/-	-/-	-/-	-/-
Scattered, moderate	-/-	-/-	-/-	-/-
Scattered, high	-/-	-/-	-/-	-/-
One-story, low	33/42	30/37	-/-	32/40
One-story, moderate	33/35	36/47	-/-	36/46
One-story, high	-/-	-/-	-/-	-/-
Two-story, low	36/42	36/48	-/-	36/44
Two-story, moderate	28/38	33/48	37/59	31/45
Two-story, high	22/32	33/47	39/44	27/38
Multi-storied, low	28/43	30/51	-/-	29/45
Multi-storied, moderate	27/36	30/48	26/50	28/40
Multi-storied, high	20/30	21/43	23/49	21/35
All	24/34	28/46	29/51	26/39

Appendix 7. Average Pre- and Post-treatment Crowning Indexes by region, ownership, density, and structure.
Treatment: 50% BA Removal.

State of Montana

Structure

	Federal	Private	Other	All
No Structure	-/-	-/-	-/-	-/-
Scattered	-/-	-/-	-/-	-/-
One-story	31/76	31/38	23/45	30/46
Two-story	27/45	29/43	32/57	28/45
Multi-storied	25/53	22/46	24/56	24/51
All	25/51	24/45	25/56	25/50

Density

	Federal	Private	Other	All
Low	32/38	28/33	34/47	31/38
Moderate	29/53	29/45	30/53	29/51
High	21/51	21/46	23/58	22/51
All	25/51	24/45	25/56	25/50

Structure/Density

	Federal	Private	Other	All
Scattered, low	-/-	-/-	-/-	-/-
Scattered, moderate	-/-	-/-	-/-	-/-
Scattered, high	-/-	-/-	-/-	-/-
One-story, low	-/-	30/32	-/-	30/32
One-story, moderate	31/76	33/41	25/42	32/49
One-story, high	-/-	19/21	21/48	20/35
Two-story, low	38/46	27/31	30/56	33/42
Two-story, moderate	29/45	31/42	32/51	30/45
Two-story, high	21/45	27/45	36/75	24/47
Multi-storied, low	29/34	29/35	37/43	30/35
Multi-storied, moderate	28/55	28/47	29/54	28/53
Multi-storied, high	21/52	20/46	22/57	21/51
All	25/51	24/45	25/56	25/50

West of the Divide

Structure

	Federal	Private	Other	All
No Structure	-/-	-/-	-/-	-/-
Scattered	-/-	-/-	-/-	-/-
One-story	31/73	25/35	23/45	26/51
Two-story	31/52	25/40	30/55	29/48
Multi-storied	27/58	21/47	24/57	25/55
All	28/57	22/45	24/56	26/54

Density

	Federal	Private	Other	All
Low	35/44	30/36	34/47	34/43
Moderate	30/57	27/42	29/54	30/53
High	24/60	19/47	22/58	22/55
All	28/57	22/45	24/56	26/54

Structure/Density

	Federal	Private	Other	All
Scattered, low	-/-	-/-	-/-	-/-
Scattered, moderate	-/-	-/-	-/-	-/-
Scattered, high	-/-	-/-	-/-	-/-
One-story, low	-/-	-/-	-/-	-/-
One-story, moderate	31/73	25/35	25/42	27/51
One-story, high	-/-	-/-	21/48	21/48
Two-story, low	37/49	29/36	30/56	33/46
Two-story, moderate	33/51	28/40	31/53	31/48
Two-story, high	25/56	22/42	27/61	24/49
Multi-storied, low	33/41	32/37	37/43	34/41
Multi-storied, moderate	29/58	27/44	29/54	29/55
Multi-storied, high	24/60	19/48	22/58	22/56
All	28/57	22/45	24/56	26/54

East of the Divide

Structure

	Federal	Private	Other	All
No Structure	-/-	-/-	-/-	-/-
Scattered	-/-	-/-	-/-	-/-
One-story	33/82	33/39	-/-	33/44
Two-story	23/40	31/44	35/59	27/43
Multi-storied	22/47	23/45	24/53	22/47
All	22/46	26/44	28/55	24/46

Density

	Federal	Private	Other	All
Low	29/32	26/30	-/-	28/32
Moderate	26/47	31/46	32/49	28/47
High	19/46	23/44	26/58	21/46
All	22/46	26/44	28/55	24/46

Structure/Density

	Federal	Private	Other	All
Scattered, low	-/-	-/-	-/-	-/-
Scattered, moderate	-/-	-/-	-/-	-/-
Scattered, high	-/-	-/-	-/-	-/-
One-story, low	-/-	30/32	-/-	30/32
One-story, moderate	33/82	35/43	-/-	35/48
One-story, high	-/-	19/21	-/-	19/21
Two-story, low	39/43	23/24	-/-	34/37
Two-story, moderate	26/40	32/43	33/49	29/42
Two-story, high	19/40	31/48	39/79	24/46
Multi-storied, low	25/28	26/33	-/-	25/29
Multi-storied, moderate	26/50	28/50	26/48	27/50
Multi-storied, high	19/47	21/44	24/54	20/47
All	22/46	26/44	28/55	24/46

Appendix 8. Average Pre- and Post-treatment Crowning Indexes by region, ownership, density, and structure.
Treatment: Comprehensive.

State of Montana

Structure

	Federal	Private	Other	All
No Structure	-/-	-/-	-/-	-/-
Scattered	-/-	-/-	-/-	-/-
One-story	28/107	32/69	30/68	31/80
Two-story	29/83	30/74	32/93	30/81
Multi-storied	25/83	24/77	25/88	25/82
All	26/84	26/76	26/89	26/82

Density

	Federal	Private	Other	All
Low	33/82	32/83	36/93	33/84
Moderate	29/82	30/72	30/75	30/78
High	22/86	21/77	23/94	22/84
All	26/84	26/76	26/89	26/82

Structure/Density

	Federal	Private	Other	All
Scattered, low	-/-	-/-	-/-	-/-
Scattered, moderate	-/-	-/-	-/-	-/-
Scattered, high	-/-	-/-	-/-	-/-
One-story, low	25/107	33/92	-/-	29/99
One-story, moderate	31/130	34/62	33/70	33/77
One-story, high	28/38	19/30	27/67	25/50
Two-story, low	36/86	33/82	34/104	35/88
Two-story, moderate	30/83	31/71	32/80	31/77
Two-story, high	22/81	27/76	39/103	25/81
Multi-storied, low	31/77	31/81	29/79	32/78
Multi-storied, moderate	29/81	29/76	29/71	29/79
Multi-storied, high	21/87	20/78	22/94	21/85
All	26/84	26/76	26/89	26/82

West of the Divide

Structure

	Federal	Private	Other	All
No Structure	-/-	-/-	-/-	-/-
Scattered	-/-	-/-	-/-	-/-
One-story	27/137	31/94	29/73	29/103
Two-story	33/88	27/90	30/104	31/92
Multi-storied	28/88	23/85	25/90	26/88
All	29/88	24/87	26/92	27/89

Density

	Federal	Private	Other	All
Low	35/89	33/95	36/93	35/91
Moderate	30/89	28/87	29/78	30/87
High	24/88	20/85	22/97	22/90
All	29/88	24/87	26/92	27/89

Structure/Density

	Federal	Private	Other	All
Scattered, low	-/-	-/-	-/-	-/-
Scattered, moderate	-/-	-/-	-/-	-/-
Scattered, high	-/-	-/-	-/-	-/-
One-story, low	23/148	34/113	-/-	30/127
One-story, moderate	31/125	25/67	33/70	29/87
One-story, high	-/-	-/-	21/80	21/80
Two-story, low	37/87	32/89	34/104	35/91
Two-story, moderate	33/93	28/92	28/96	31/93
Two-story, high	25/80	23/88	26/114	24/89
Multi-storied, low	33/86	34/94	39/79	35/86
Multi-storied, moderate	30/87	29/85	29/72	29/85
Multi-storied, high	24/89	19/85	22/96	22/90
All	29/88	24/87	26/92	27/89

East of the Divide

Structure

	Federal	Private	Other	All
No Structure	-/-	-/-	-/-	-/-
Scattered	-/-	-/-	-/-	-/-
One-story	29/77	33/58	32/53	32/63
Two-story	26/80	32/64	35/74	29/72
Multi-storied	23/79	24/70	24/77	23/75
All	24/79	27/67	29/75	25/74

Density

	Federal	Private	Other	All
Low	30/73	31/69	-/-	30/71
Moderate	27/74	32/64	33/67	30/69
High	20/84	23/70	27/81	21/79
All	24/79	27/67	29/75	25/74

Structure/Density

	Federal	Private	Other	All
Scattered, low	-/-	-/-	-/-	-/-
Scattered, moderate	-/-	-/-	-/-	-/-
Scattered, high	-/-	-/-	-/-	-/-
One-story, low	27/66	30/60	-/-	29/63
One-story, moderate	33/139	36/61	-/-	36/70
One-story, high	28/38	19/30	32/53	26/40
Two-story, low	34/85	34/74	-/-	34/81
Two-story, moderate	28/76	32/62	35/68	31/68
Two-story, high	20/82	30/66	36/89	25/76
Multi-storied, low	28/66	28/67	-/-	28/66
Multi-storied, moderate	27/71	30/68	28/62	28/69
Multi-storied, high	20/85	21/71	24/80	20/80
All	24/79	27/67	29/75	25/74